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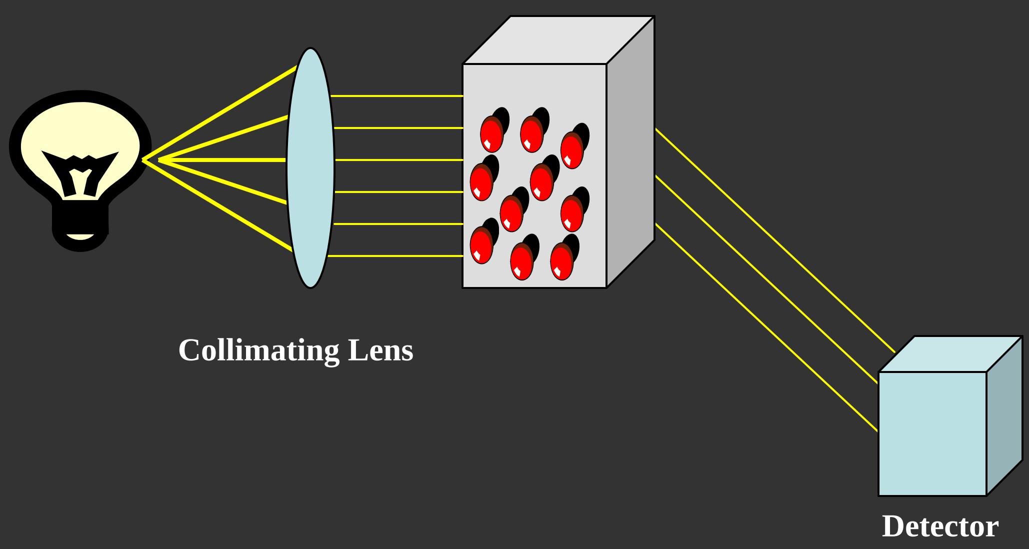
Development of a Robust Planetary Polarization Nephelometer

Principle Investigator - Don Banfield
Lead Optical Engineer - Adam Saltzman

What is a Nephelometer?

- A Nephelometer is an optical tool used to detect and characterize distributions of aerosols.
- Traditional nephelometers use a single light source to detect the amplitude scattering phase function of aerosols, a nephelometer of this sort was included in the Galileo mission.



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Goals of Our Nephelometer

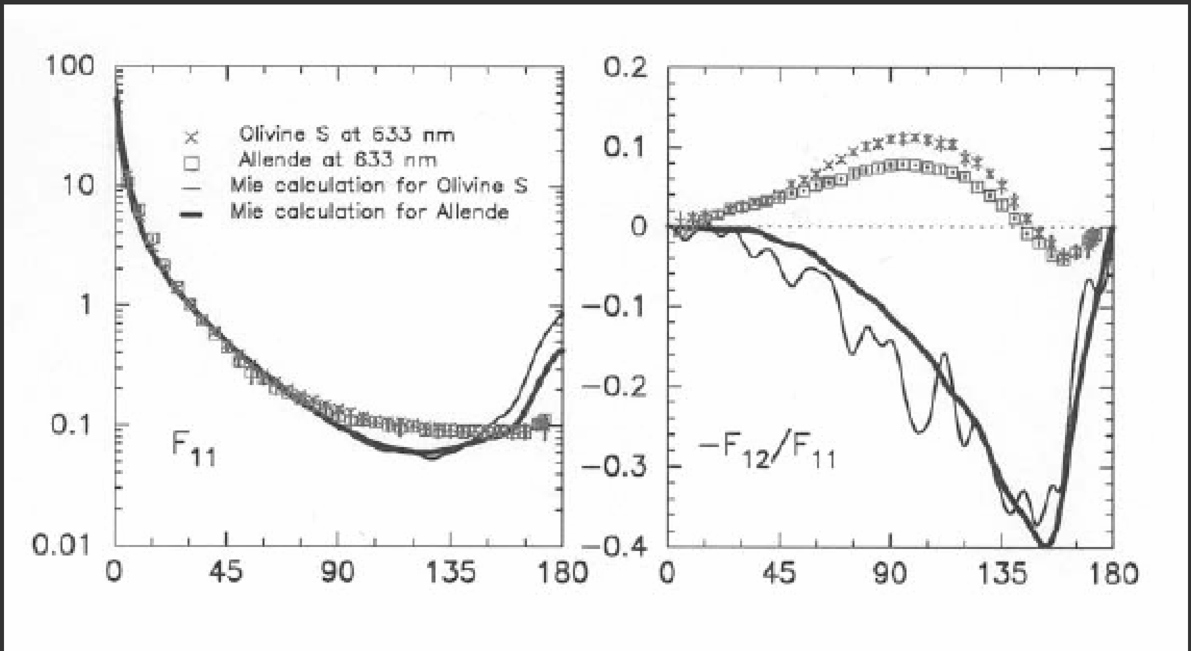
- To measure distributions of aerosols ranging in size from one (Venus upper haze) to ten (Jupiter water clouds) microns in radius with densities ranging from one (Venus upper haze) to one thousand (Jupiter Water Clouds) particles per cm^3.

- This system will be able to help answer some interesting questions about the atmospheres of Jupiter and Venus.
  - Why is Jupiter red, What are the chromophores in Jupiter's atmosphere.
  - Is the visible cloud deck of Jupiter composed of 700mbar ammonia, or 1.5 bar ammonium hydrosulfide.
  - How much of the sulfuric acid in Venus atmosphere is in an aerosol form.
  - What is affecting the equilibrium CO_2 chemistry on Venus.

- Our device is robust, it is designed for hostile environments, with tested telecommunication components in a cavity isolated from the environment with only collection and transmission optics exposed. A device like this can be used to characterized the atmospheres of the other gas giants, Titan is a very good candidate, and there are applications for distributions of non spherical particles, including the dust on mars, or terrestrial pollutants.

Polarization Nephelometery, Why Is it Important

- Amplitude is not the only information available to a nephelometer, scattered light contains amplitude, polarization and spectrum.
- Polarization can be used to uniquely identify particles where amplitude scattering alone is not enough.



Experimental and theoretical results for dust like Allende Meteorite and Mg-Rich Olivine Samples.

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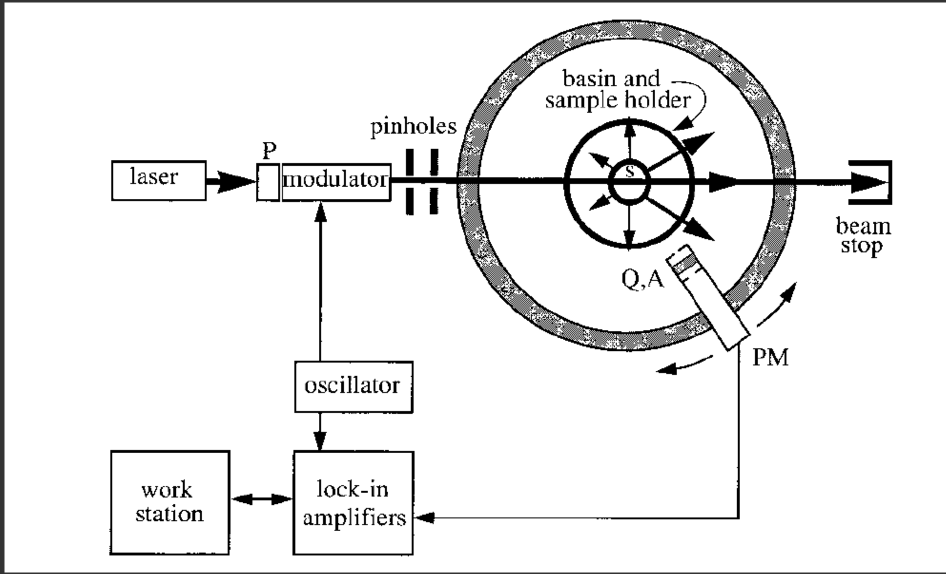
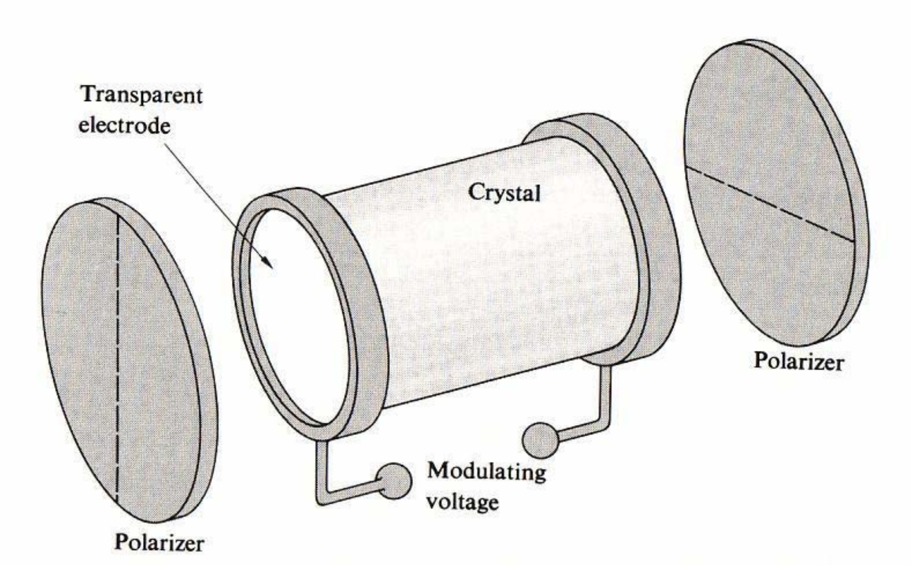
Our Role and Novel Technology

- Initially Hunt and Huffman, and recently Hovenier et al., demonstrated polarization nephelometery in a lab setting
- Relies on a voltage and temperature sensitive nonlinear optical device called a Pockels cell which is unfit for field applications





- We are developing a robust technique to create the same modulation effect using two power modulated solid state lasers.
- Currently we are in the process of building a proof of concept prototype which we hope to be able to test on terrestrial aerosols by the end of next year.

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Modulated Illumination and Their Effect on the Retrieved Signal

- A Pockels cell Nephelometer – The highlighted term represents the power received after scattering.

$$ScatterP = \underbrace{\begin{bmatrix} F11 & F12 & 0 & 0 \\ F12 & F11 & 0 & 0 \\ 0 & 0 & F33 & F34 \\ 0 & 0 & -F34 & F33 \end{bmatrix}}_{\text{Scattering off a spherical particle}} \cdot \underbrace{\begin{bmatrix} 1 \\ 0.863050\cos(2\,\omega t) \\ 0 \\ 1.03830\sin(\omega t) \end{bmatrix}}_{\text{Pockels Cell illumination beam}} = \begin{bmatrix} \boxed{F11 + 0.863050\,F12\cos(2\,\omega t)} \\ F12 + 0.863050\,F11\cos(2\,\omega t) \\ 1.03830\,F34\sin(\omega t) \\ 1.03830\,F33\sin(\omega t) \end{bmatrix}$$

- Modulated Laser Nephelometer – The highlighted term is theoretical scattered power, nearly identical to the Pockels cell system

$$ScatterC = \begin{bmatrix} F11 & F12 & 0 & 0 \\ F12 & F11 & 0 & 0 \\ 0 & 0 & F33 & F34 \\ 0 & 0 & -F34 & F33 \end{bmatrix} \cdot \underbrace{\begin{bmatrix} 1 \\ \cos(\omega\cdot t) \\ 0 \\ 0 \end{bmatrix}}_{\text{Illumination from two } \pi/2 \text{ phase shifted, sinusoidal modulated orthogonally polarized lasers}} = \begin{bmatrix} \boxed{F11 + F12\cdot\cos(\omega\cdot t)} \\ F12 + F11\cdot\cos(\omega\cdot t) \\ 0 \\ 0 \end{bmatrix}$$

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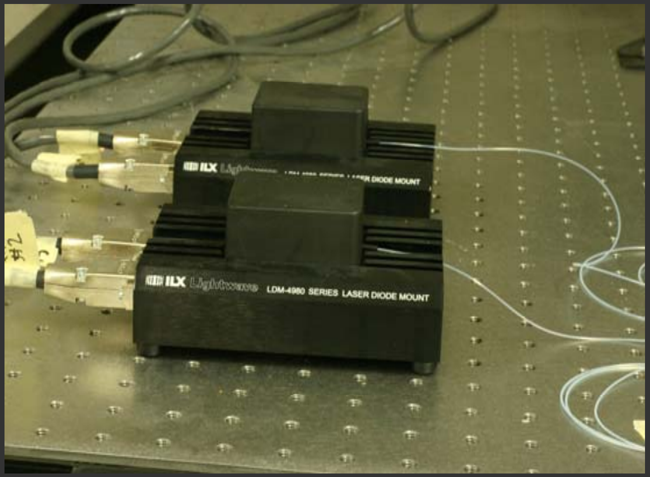
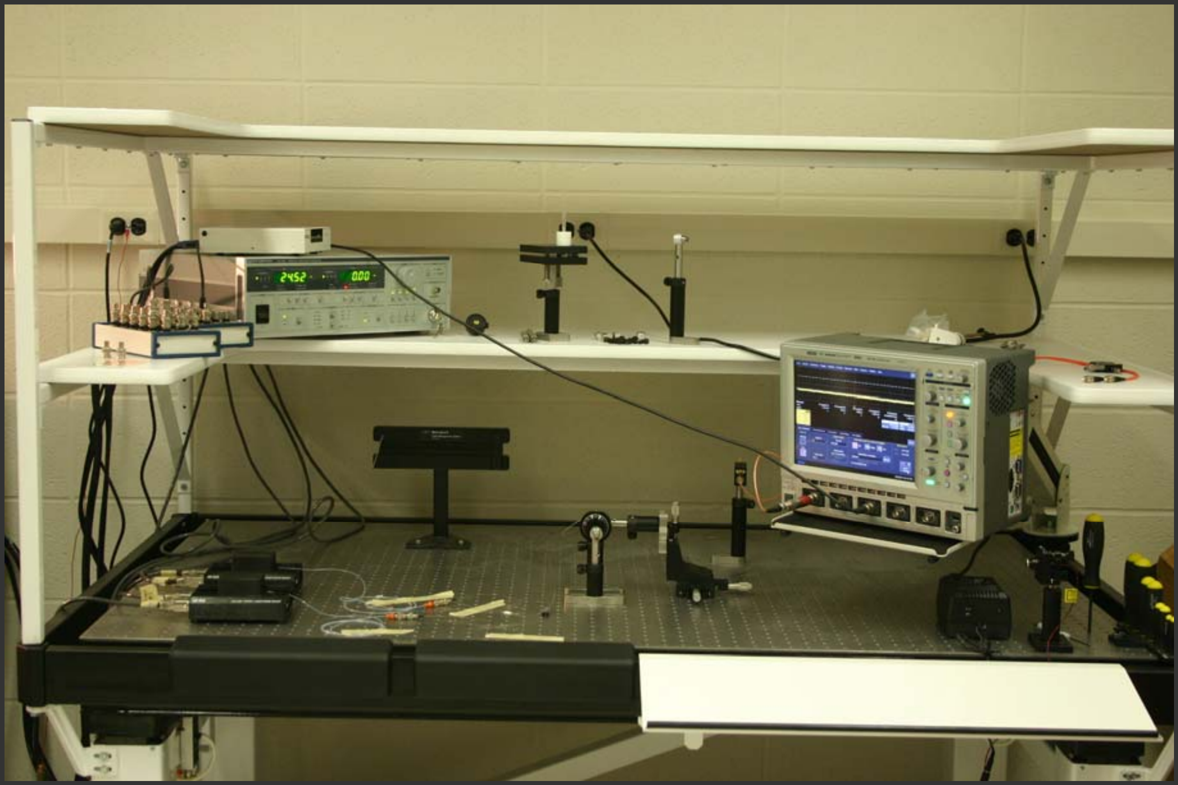
Experimental Results- Equipment and Laboratory Setup



- Robust 20mw butterfly coupled DFB lasers capable of GHz modulation.



- Experimental Illumination Setup – A linear polarizer mounted in a manual rotation stage is rotated every ten degrees and the signal is recorded on a photodiode.

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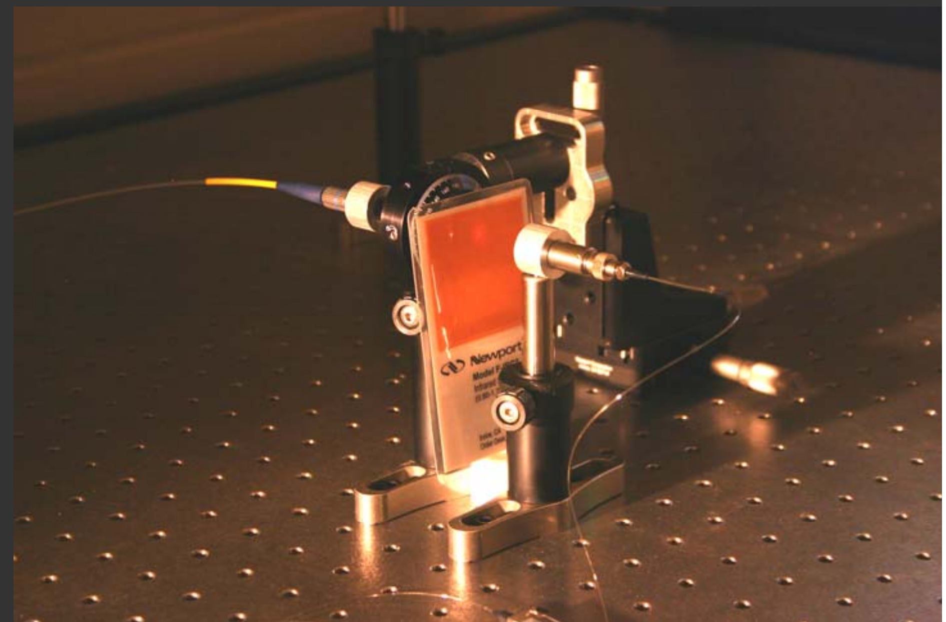
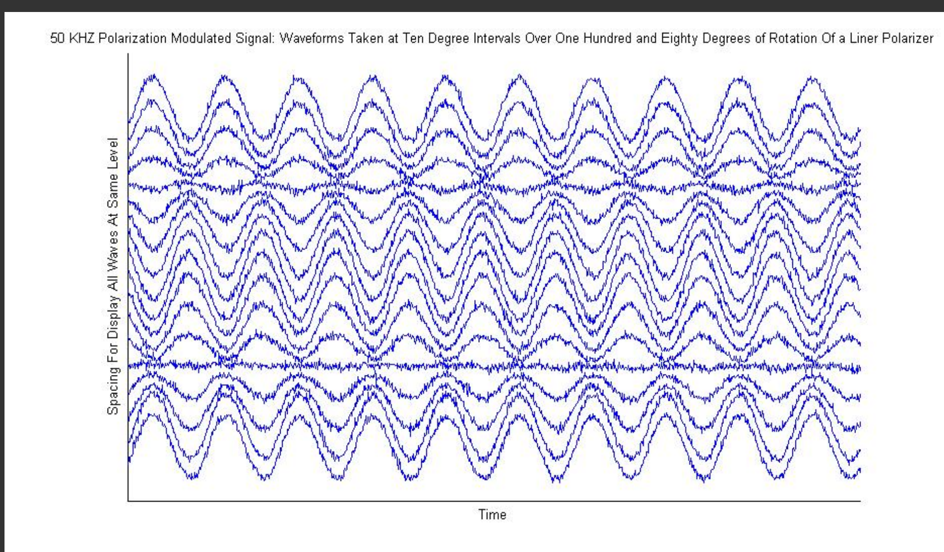
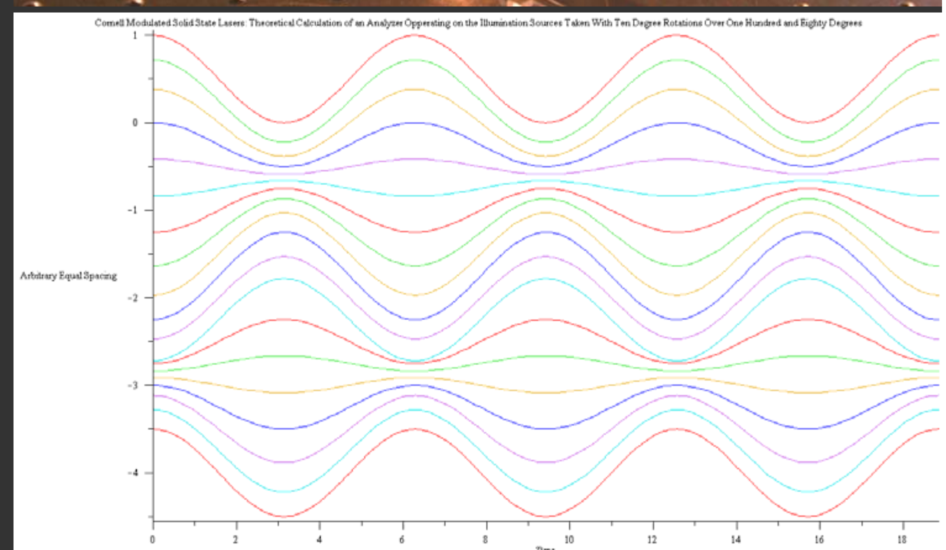
Measurements and Results of Modulated Beam Experiments

- By taking measurements of our signal at different angular rotations of the polarizer we see that our experiment agrees very well with theory.







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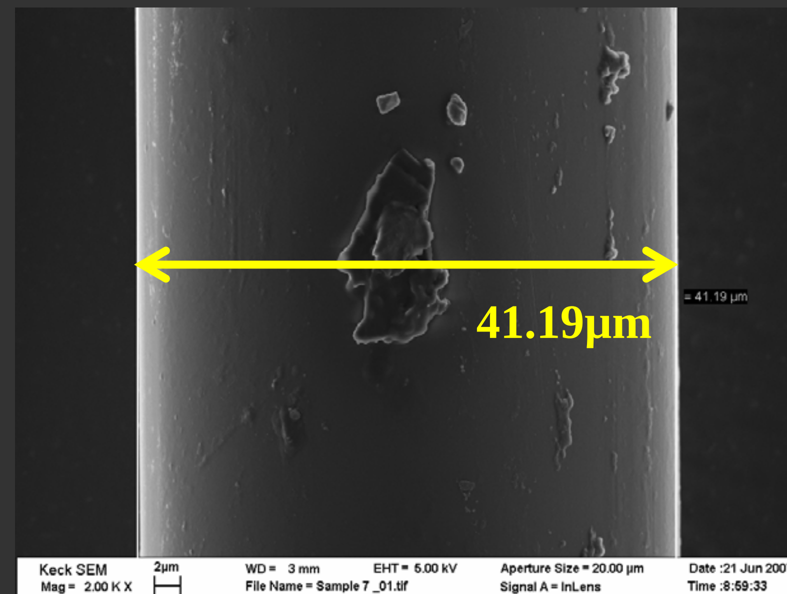
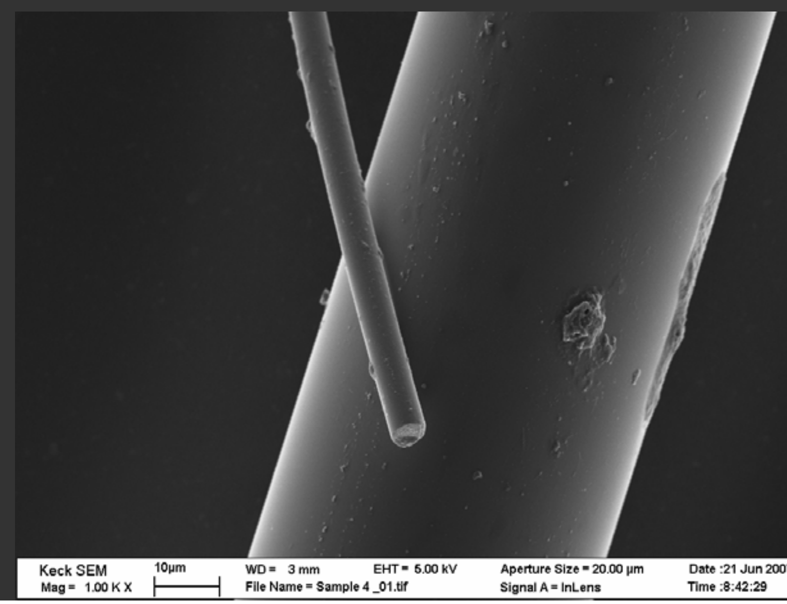
Cylindrical Calibration Targets

- Verifiable - Electron microscope images
- Stationary - Aerosol distributions are at best a mobile statistical distribution

- Correct Size– Polarization effects only significant on cylinders with diameters on the order of the wavelength





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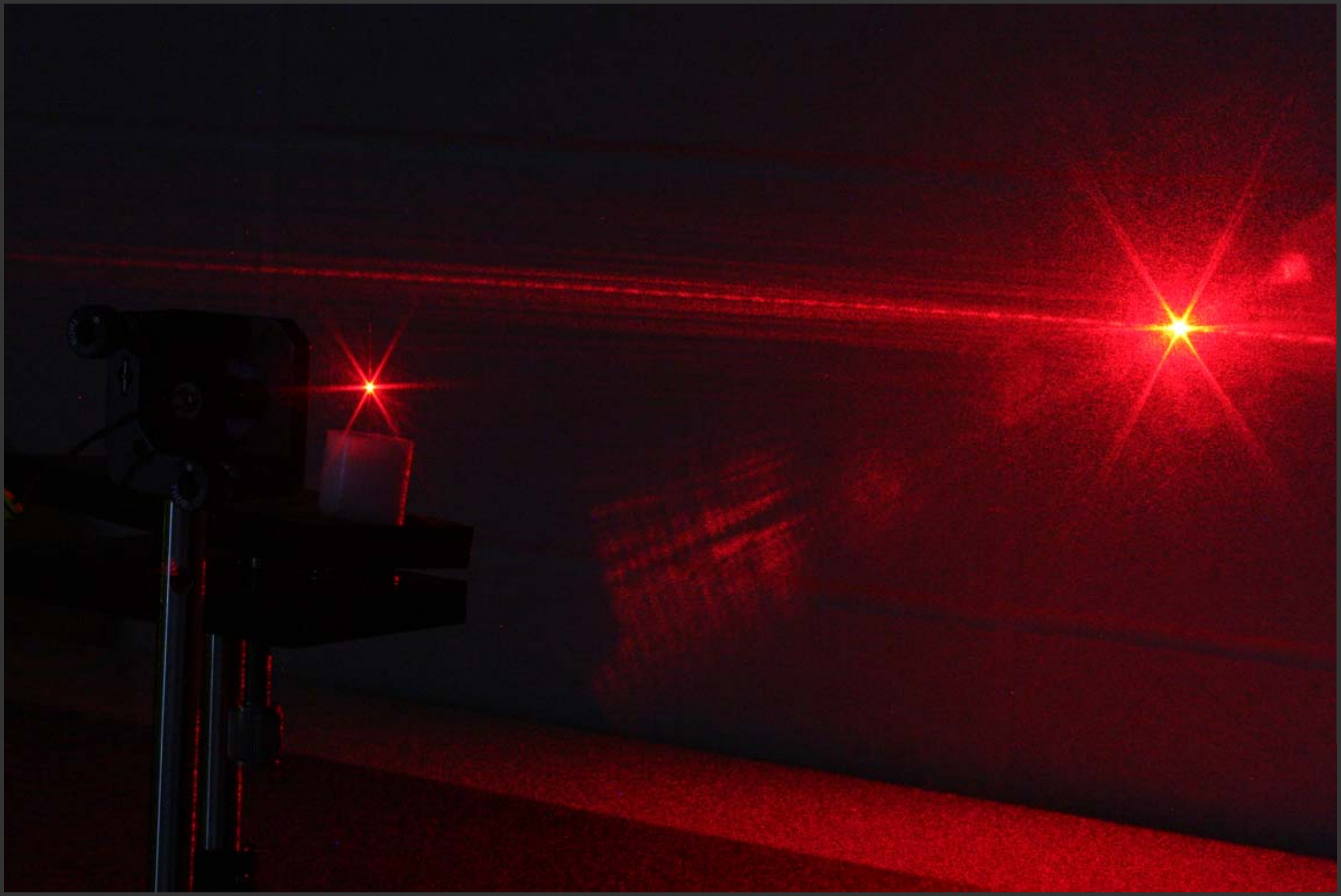
Aligning Fiber Tilt

- The fiber needs to be perpendicular to the illumination. We used this diffraction pattern at many angles to adjust the alignment.



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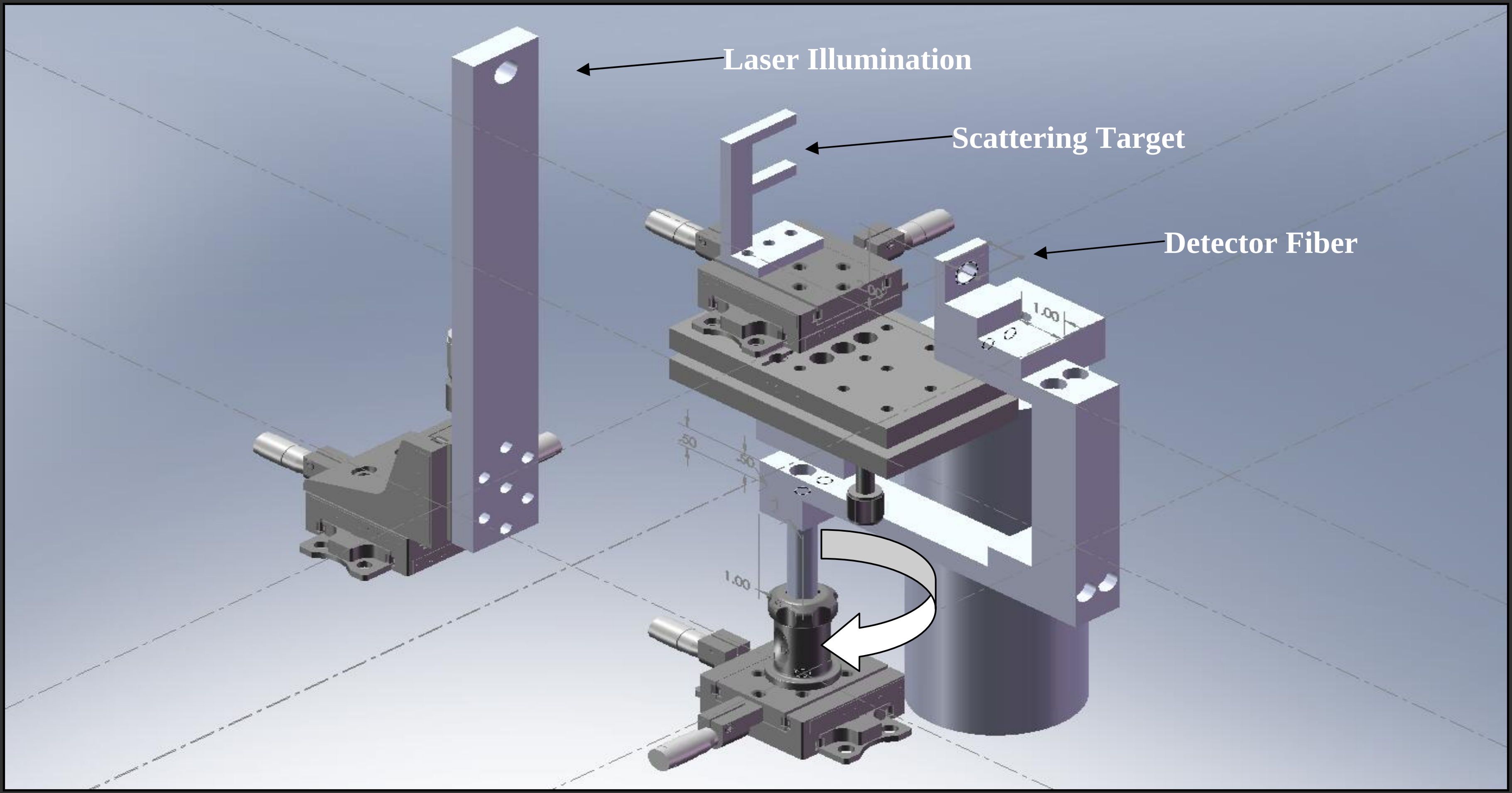
Mechanical Design and Measuring a Full 180 Degree Phase Function



Mechanical Design – Includes an adaptable rotating detector arm, a laser mount, a tilt stage and a series of precision alignment stages to get the maximum symmetric scattering from the target.

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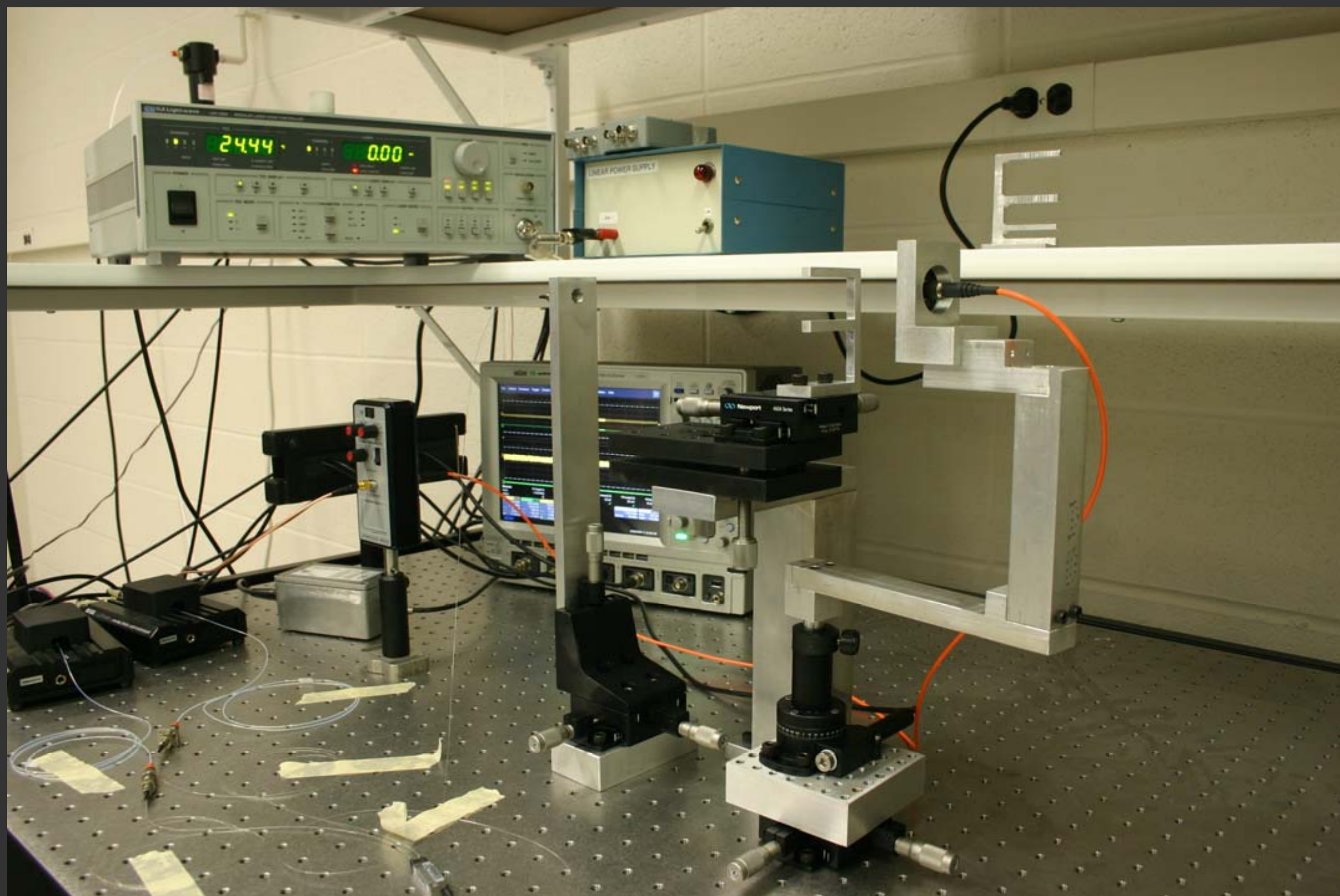
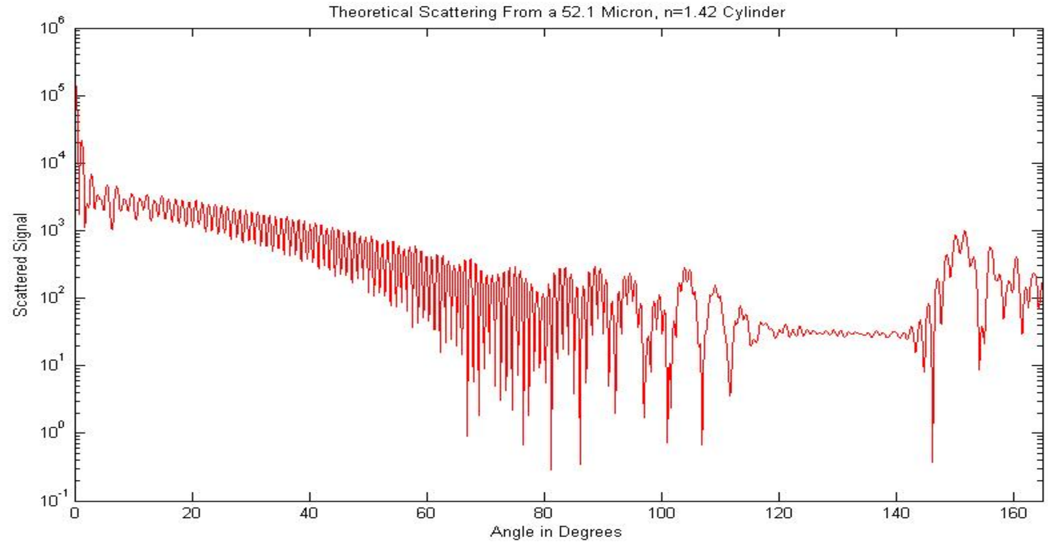
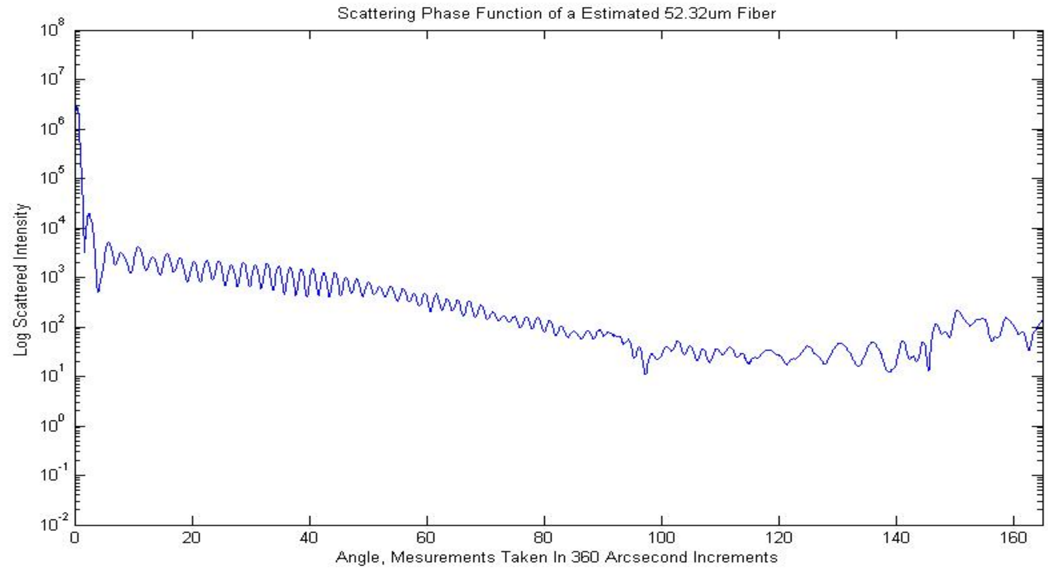
Realization of Rotating Design



- Fiber Experimental Setup - Automated rotation stage and a 200 μm multimode fiber which allows for 0.12 degree sampling resolution.

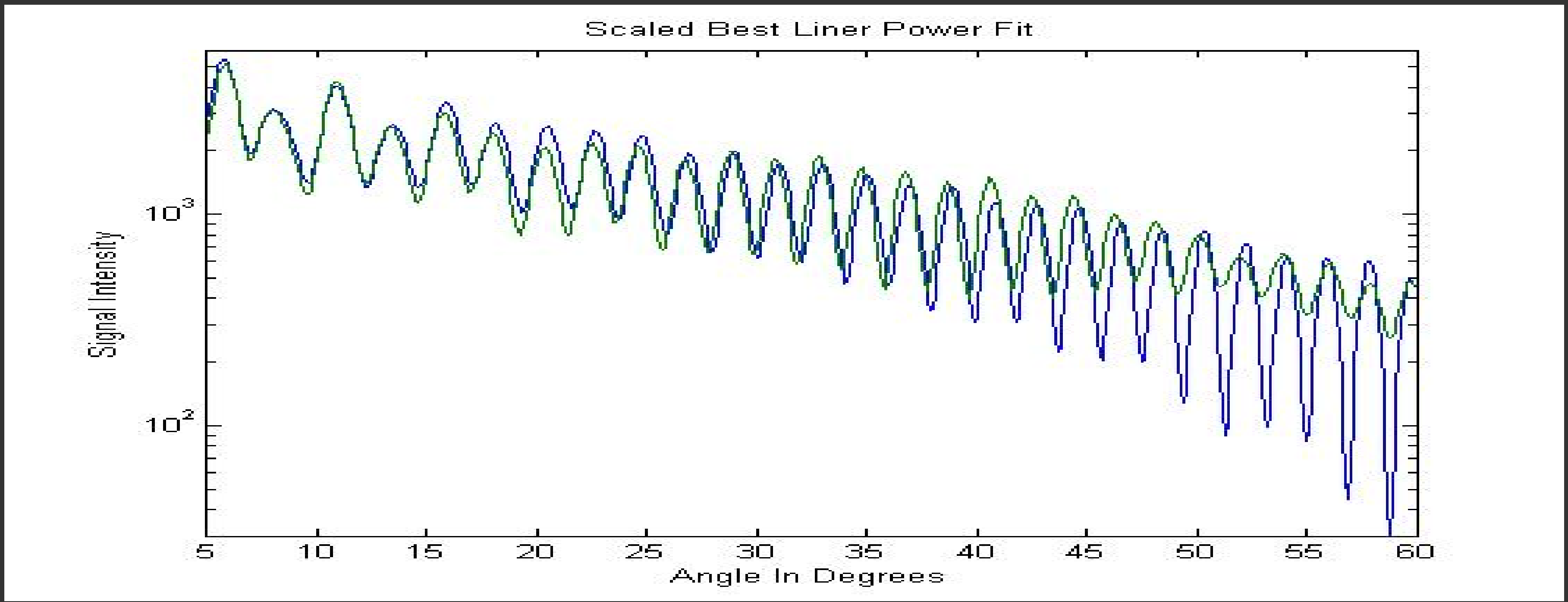
Comparison of Simulation and Real Data for a 52.1um Fiber





- **Top – Simulation of a 52.1μm fiber**
- **Bottom – Real experimental data for a full phase function**

Best Liner Fit



- χ^2 fit estimates a fiber radius of 52.1µm a 0.42% percent error from our electron microscope estimate of 52.32 µm, and a reasonable 1.42 index of refraction
- Our χ2 analysis shows we can estimate the radius to within .2µm and the index to within .02

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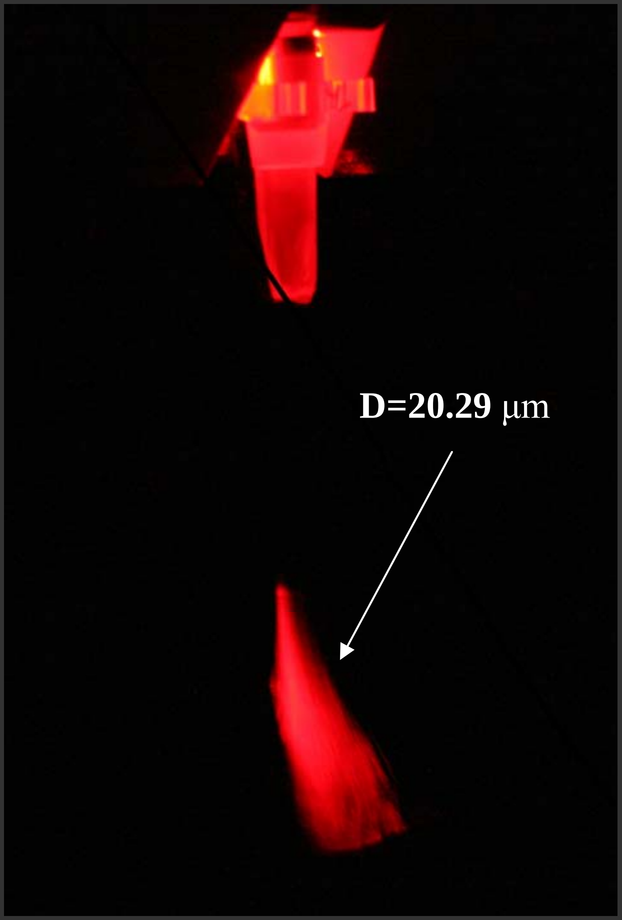
HP Aerosol Generator



- Aerosol distributions from 12 to 82 µm in diameter
- Continuous operation between 5 and 15kHZ for realistic cloud densities

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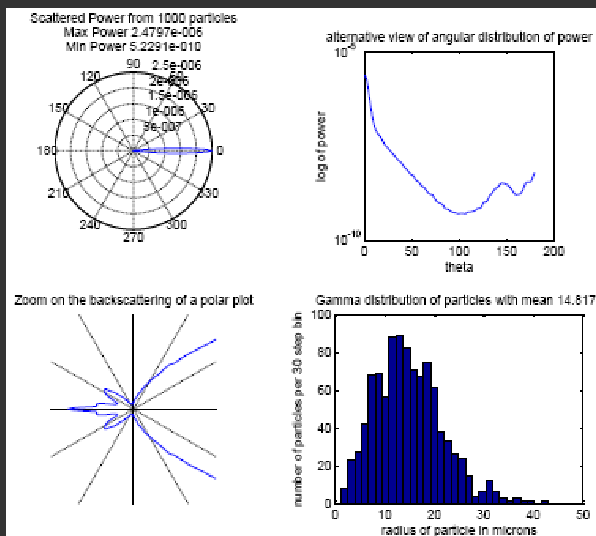
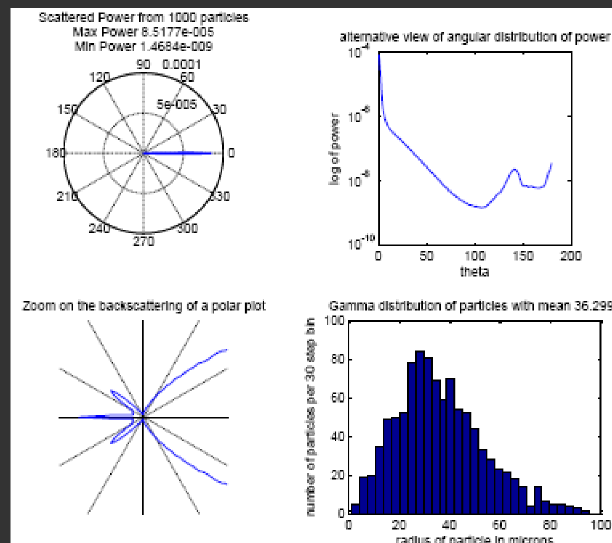
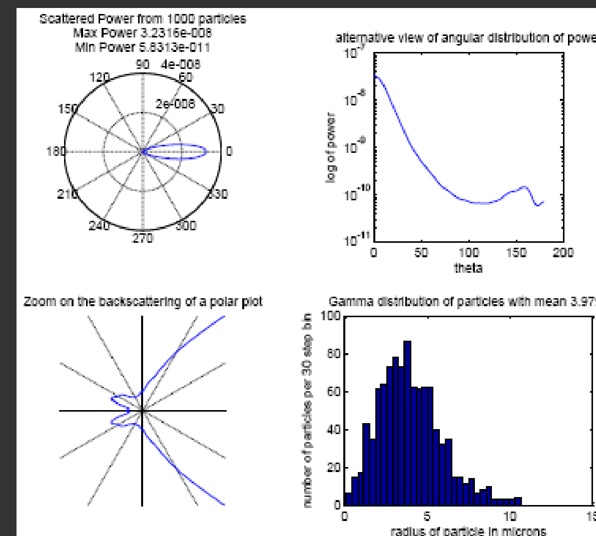
Theoretical Modeling of Particle Distributions



Scattering Intensity for 36 micron Particles



Scattering intensity for 15um particles



Scattering intensity for 4 micron particles

- Gamma distributions of 1000 water particles with different mean diameters
    - Small particles are much more isotropic than large particles
    - Backscatter has a unique shape for each mean particle size.

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Conclusions

- Progress
  - We are well on our way to building a robust polarization nephelometer that can be used on a variety of future planetary missions.
- Robust Design
  - No moving parts
  - Optical components will be sealed inside a isolated cavity protected from the environment.
  - Lasers and detectors are commercial failure tested telecommunications components.
  - It is a real field instrument that can be used in the hostile atmospheres of venues and Jupiter, and in dust storms on mars.
- More Information
  - Polarization
  - Spectral components